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Shade Material Evaluation Using a Cattle Response Model

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Abstract. *Cattle produced in open feedlots are vulnerable to a variety of weather events; under certain conditions heat events can be especially detrimental. Shade structures are often considered as one method of reducing cattle stress. A variety of shading materials are available; selection of a suitable material is difficult without data that quantify effectiveness of the materials on stress reduction. A summer study was initiated using instrumented shade structures in conjunction with meteorological measurements to estimate relative effectiveness of various shade materials. The shade structures were 3.6 m by 6.0 m by 3.0 m high at the peak and 2.0 m high at the sides. Polyethylene shade cloth was used in three of the comparisons and consisted of 100%, 80%, and 50% effective shading. Additionally, one of the structures was fitted with a poly snow fence instead of shade cloth. Each shade structure contained a solar radiation meter to measure radiant energy received under the shade material. Additionally, meteorological data were collected as a non-shaded treatment and included temperature, humidity, wind speed, and solar radiation. Analyses of the collected data focused on a physiological model that predicts cattle respiration rate based on relative humidity, ambient temperature, solar radiation and wind speed. An associated heat stress*

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index was used to determine the effectiveness of the shading options. Analyses of the data revealed that time spent in the highest stress category was reduced by all shade materials. Moreover, significant differences ($p<0.05$) existed between all shade materials (compared to no-shade) for hourly summaries during peak daylight hours.

Keywords. Feedlot, Heat, Weather, Threshold, Temperature, Humidity, Shade materials

Introduction

Cattle have remarkable ability to cope with environmental stressors, and within limits can adjust physiologically, behaviorally, and immunologically to minimize adverse effects (Hahn, 1999). High ambient temperature (T_a , C) and humidity, in combination with a solar load and low air movement, can exceed stressor limits with resulting in loss of productivity and even death of the animal (Hahn and Mader, 1997; Gaughan et al., 2000; Lefcourt and Adams, 1996; Mader et al., 1999). Recognizing the potential severity of a heat stress event, and providing access to stress-reducing measures such as shade structures, can increase animal performance and reduce death losses.

The use of shade structures can reduce the solar load by as much as 30% (Bond and Laster, 1975), and has received attention as a means of mediating summer heat loads (Brown-Brandl, et al., 2005; Eigenberg et al., 2005; Bond and Laster, 1975; Blackshaw and Blackshaw, 1994). Parker (1963) evaluated the effectiveness of 14 combinations of shading materials (variety of metal roofing material that were either natural or painted, and various ceiling materials under the roof) using a radiometer, thermocouples, and black globe thermometers; however, no direct animal response data were collected.

Animal response to shade was difficult to measure by traditional methods of growth and feed conversion. Animal variability and dynamics, coupled with uncontrollable periods of stressful conditions, made cause/effect evaluation difficult or impossible. Development of an animal response model was later based on data collected within environmental growth chambers under well controlled periods of stress (Hahn, et al., 1997). The growth chambers allowed development of tools to measure animal dynamics; two primary measures were respiration rate (RR) and body temperature. Using animal responses to the stressful conditions in well-controlled chambers, measurements on animals in uncontrolled stressful environments were made with the same dynamic measurement tools. Response measures of body temperature and RR have been collected in outdoor shaded and un-shaded pens with additional measurements of temperature, humidity, solar radiation, and wind speed (Brown-Brandl, et al., 2005). The work in these naturally occurring stressful environments led to a model that relates four environmental factors (temperature, solar radiation, wind speed, and humidity) to RR (Eigenberg, et al., 2005). The use of the physiological model to evaluate shade material provides a measure directly related to animal stress.

In addition to a more representative animal response measurement, the variety of shade materials currently available have characteristics made different from those tested in the 1960s. Shade materials available today are typically made of polyethylene material and offer flexibility, lower cost and lighter weight than some of the more traditional building materials. The flexibility and light weight offer innovative structural components for fabrication of shaded facilities.

Objective

It is the objective of this work to evaluate several shade materials for feedlot cattle using predicted stress response of the animal based on measured environmental parameters.

Materials and Methods

During the 2006 summer, a study was conducted at the USMARC. Shade structures were built and instrumented with data collected through the month of August. The Shade treatments were provided by self-supporting shade structures constructed of metal tubing and 0.3 mm thick poly-vinyl shade cloth that provided a gradation of shade including 100, 80, and 50% shade.

Additionally, a partial shade was provided using a snow-fence in lieu of the shade cloth; this covering provided an estimated 25% shade. The shade structures were built in concrete surfaced pens (3.6 m × 12 m) that were separated by 3.6 m. Pens were oriented north/south. The structures covered the south end of the Shade treatment pens to a length of approximately 6 m, and across the full width of 3.6 m. The structures were 3 m high at the peak, with the east side extending down to a height of 2.4 m, and the west side to a height of 1.8 m.

Instrumentation was placed under all treatments (Fig. 1); the no shade treatment included a commercial weather station (Davis Instruments, Hayward, CA, USA) which measured solar radiation, ambient temperature, relative humidity, and wind speed every five minutes. All other treatments (25%, 50%, 80%, and 100% shade) recorded solar radiation (Davis Instruments, Hayward, CA, USA) measurements every five minutes.

Estimated RR was generated based on a model developed by Eigenberg et al. (2005) and shown as equation 1:

$$RR = 5.4 \cdot T_a + 0.58 \cdot RH - 0.63 \cdot WS + 0.024 \cdot RAD - 110.9 \quad (\text{equation 1})$$

Where: RR is the respiration rate of cattle, breaths per min

T_a is ambient temperature, °C

RH is relative humidity, %

WS is wind speed, m/s

RAD is solar radiation, Watt/m²

This equation was used to generate estimated RR values under each of the shade treatments to help assess the actual impact of shade on feedlot cattle. Data were combined from each treatment to generate 10 minute averages that were synchronized. The meteorological data (temperature, humidity, wind speed) were used in common for all treatments, with solar radiation data being the response variable to each shade treatment. The combined data were used to predict estimated RR for each treatment.

Additionally, thresholds were established (Eigenberg et al., 2005) for ranges of RR. These values are:

Normal	$RR \leq 85 \text{ BPM}$
Alert	$85 < RR \leq 110 \text{ BPM}$
Danger	$110 < RR \leq 133 \text{ BPM},$
Emergency	$RR > 133 \text{ BPM}$

The threshold values were applied to the estimated RR to establish the shade treatments effectiveness.

The estimated RR data were analyzed using SAS PROC GLM Least Squares Means (SAS, 2000) for effect of treatment by hour. The statistical analyses also created probability tables allowing each treatment to be tested against the control treatment. Mean values with standard errors of all treatments were also generated.

Results and Discussion

The shades and equipment were set up and made operational on August 9, 2006; data were collected through August 29, 2006. The weather provided limited opportunity to test the effectiveness of the evaluation method. Figure 2 shows the record of solar radiation and ambient temperature for the experimental period. Greater potential for heat stress occurs on the days with high temperatures and high solar loads. This analysis will focus on two days early in the study which had high solar radiation and moderately high temperatures, August 11 and 12 (Day of year 223 and 224). Estimated RRs were computed for all treatments on ten-minute intervals over the two days of interest and are plotted in figure 3. The estimated RRs shown in figure 3 display distinct patterns associated with each treatment. Statistical comparisons were computed based on hourly averages using SAS, and the results (including standard errors) summarizing the two days of the study are shown in figure 4. All treatments show significant mean differences by all treatments when compared to the no-shade control; the estimated RRs decline with increasing shade cover (Table 1). The variability as measured by the standard error is relatively small for all treatments, with the exception of the snow fence shade material. The checkerboard pattern of the snow fence created the high variability as indicated by the associated standard error.

Figure 5 (Eigenberg et al., 2005) is a plot resulting from a study conducted in 2001 using feedlot steers. The steers in that study were equipped with automated RR monitors measuring RR every 15 minutes 24 hours/day. Figure 5 was derived from that feedlot steer RR data as a summary of eight experimental periods, with a length of 4.5 days each. That same dataset (Eigenberg et al., 2005) was used to develop equation 1. Now we see that applying equation 1 to meteorological datasets to predict respiration rates (Fig. 4) produces an estimated response that appears similar to the actual feedlot steer data. Comparison of figure 4 and figure 5 supports a physiological model approach to shade material evaluation. The use of RR to determine shade effectiveness allows critical evaluation of a material's ability to reduce animal thermal stress.

A comparison was made of time spent in each of the four thermal stress categories. The data were examined on 10-minute intervals and only midday data considered (10:00 am – 7:00 pm), with the resulting stress being cumulated in one of the four stress categories. The total time spent was converted to percentages with the results displayed in figure 6. The two days analyzed (Day of year 223 and 224) represented relatively mild summer conditions, but nevertheless revealed some interesting patterns. One-hundred percent shade cloth reduced the estimated stress level (based on solar radiation reduction) so that the cattle were exposed to the Normal category environmental condition 100% of the time. Figure 6 shows that eighty percent shade cloth showed a small amount of time spent in the Alert category (about 15%), and 85% in the Normal category. Fifty percent shade cloth resulted in much more time in the Alert category (about 72%), and 28% in the Normal category. The snow fence saw the first occurrence of the Danger category (about 5%), with Alert at 75%, and Normal 20%. The reference conditions of no shade resulted in about 34% of the time spent in Danger, 59% in Alert, and 7% in Normal for this selected period.

Generally, any of the shade materials reduced the thermal stress levels compared to an open lot; the snow fence reduced the time in the Danger category by a factor of nearly seven. Shading of 50% or more completely eliminated time spent in the Danger category. The 80% and 100% shade material were required to considerably reduce or eliminate time in the Alert category.

Eighty percent shade cloth costs approximately 60% more than fifty percent shade cloth; snow fence costs approximately 50% less than fifty percent shade cloth. The snow fence is the least

expensive and may have additional advantages of catching less wind, as well as less chance for snow accumulation. Many factors must be considered in the design of a shade structure; this preliminary work may help direct future research efforts.

Conclusion

Several shade materials were evaluated using environmental measurements, which were then applied to a cattle physiological model. All of the tested shade materials reduced predicted heat stress and the associated time spent in more stressful conditions, when compared to the no-shade control treatment. The results represented in this paper are preliminary and a follow-up study with similar protocol is planned with exposure to longer periods of potential heat stress. Additionally, a study is planned to validate this methodology by evaluating feedlot cattle response under selected shade materials.

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Table 1. Mean values as determined by SAS PROC means shown with standard errors.

Time/ Trmt	10	11	12	13	14	15	16	17	18
Open,	92.5 ^a	101.4 ^a	109.4 ^a	113.1 ^a	112.9 ^a	110.1 ^a	105.0 ^a	99.9 ^a	92.6 ^a
Est RR	3.2	4.0	3.1	2.0	0.9	2.2	2.2	2.5	2.2
Snow	87.9 ^b	96.3 ^b	96.1 ^b	104.2 ^b	104.8 ^b	98.5 ^b	99.2 ^b	94.9 ^b	90.2 ^b
Est RR	3.3	6.1	9.4	4.7	4.7	6.9	2.9	3.6	1.2
50%	82.5 ^c	90.9 ^c	95.1 ^c	96.9 ^c	99.5 ^c	97.5 ^c	93.2 ^c	92.1 ^c	88.7 ^c
Est RR	3.0	2.7	2.1	1.5	0.9	2.1	3.9	2.1	1.6
80%	77.0 ^d	83.4 ^d	85.7 ^d	88.9 ^d	89.8 ^d	87.6 ^d	87.4 ^d	86.4 ^d	84.6 ^d
Est RR	2.5	2.9	3.3	1.94	1.0	2.9	1.6	1.6	0.8
100%	75.7 ^e	76.3 ^e	78.9 ^e	80.9 ^e	81.3 ^e	81.1 ^e	80.5 ^e	81.4 ^e	81.2 ^e
Est RR	5.6	2.7	2.3	1.9	1.1	1.7	1.6	0.8	0.5

Superscript letters indicate that the means are significantly different from the control treatment of no shade ($p < 0.05$)

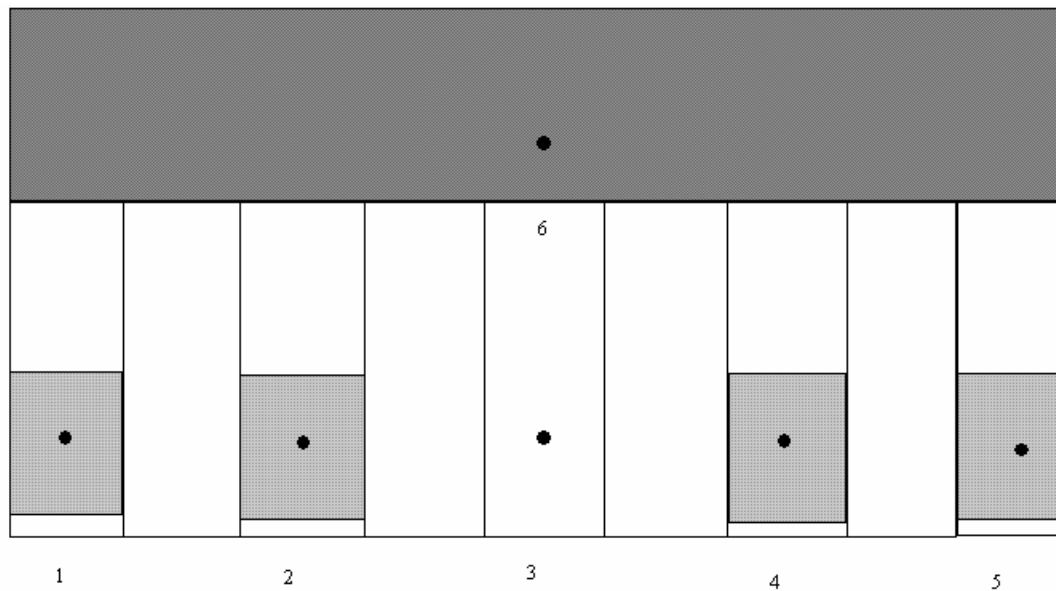


Figure 1. Drawing of shade material layout. Position 3 was location of weather station that collected wind speed, relative humidity, solar radiation, and ambient temperature as reference for treatments. The treatment locations were 1) 100%, 2) 80%, 3) open (no-shade), 4) 50%, 5) snow fence and location 6 was under an existing metal shed (data not reported).

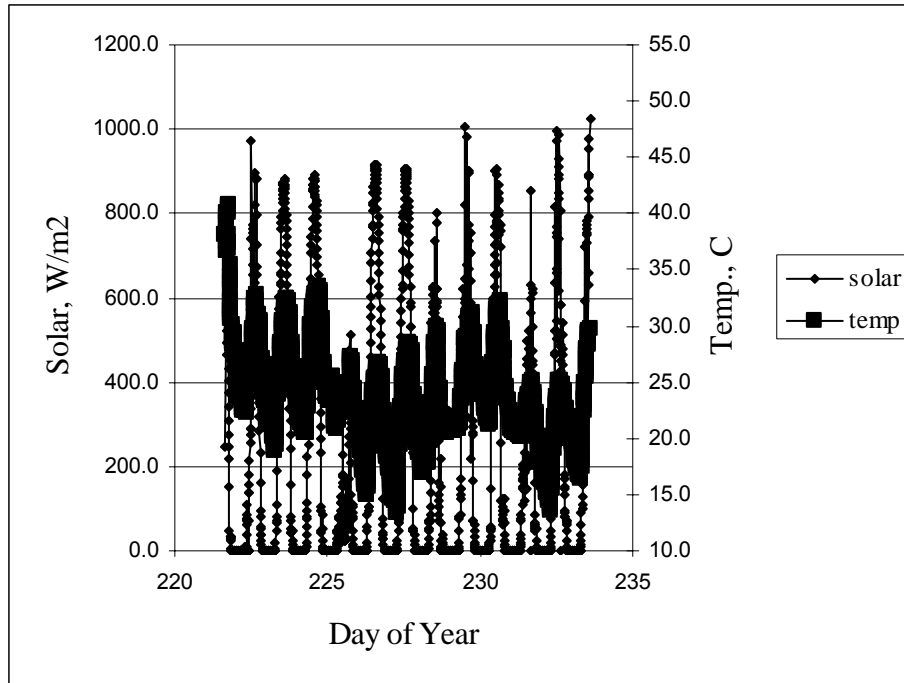


Figure 2. Record of solar radiation and ambient temperature for the experimental period. Greater potential for heat stress occurs on days with high temperatures and high solar loads; days 223 and 224 were chosen for analyses.

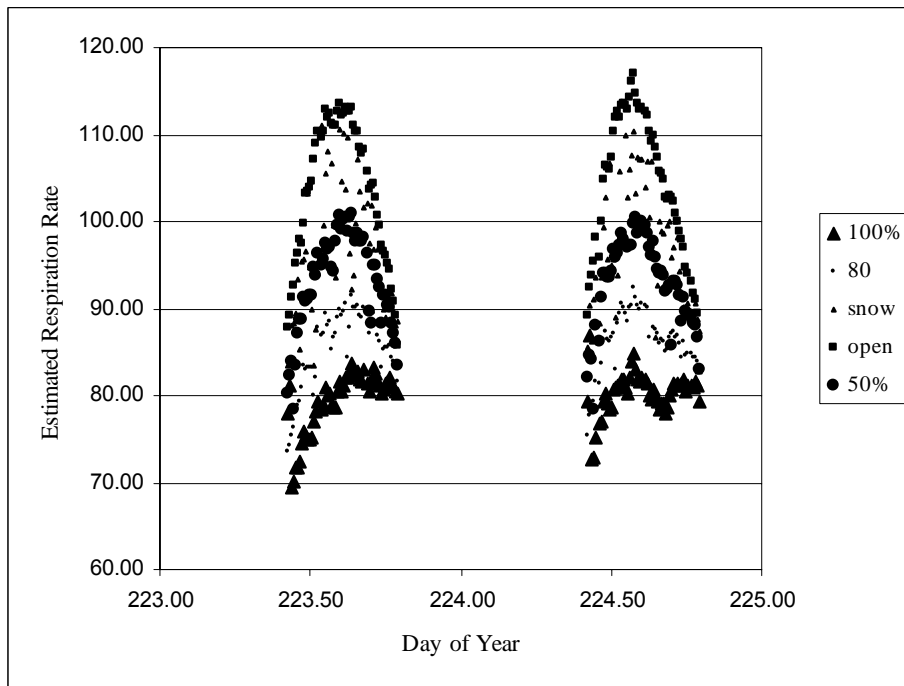


Figure 3. Estimated respiration rates were computed from physiological model for all treatments on ten-minute intervals over the two days of interest.

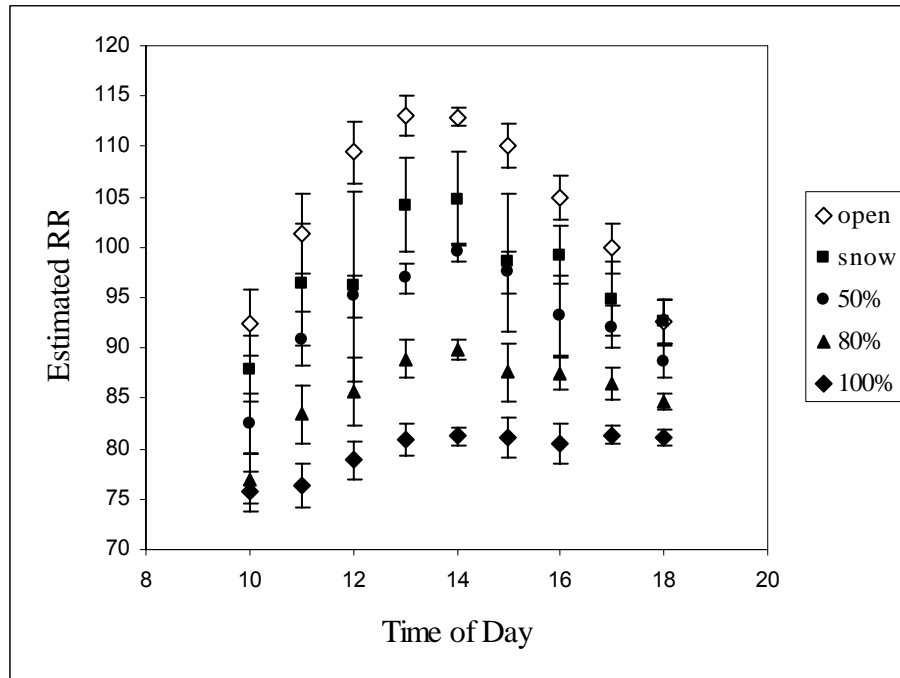


Figure 4. Hourly averages were computed using SAS and the results (including standard errors) summarizing the two days of the study are plotted here.

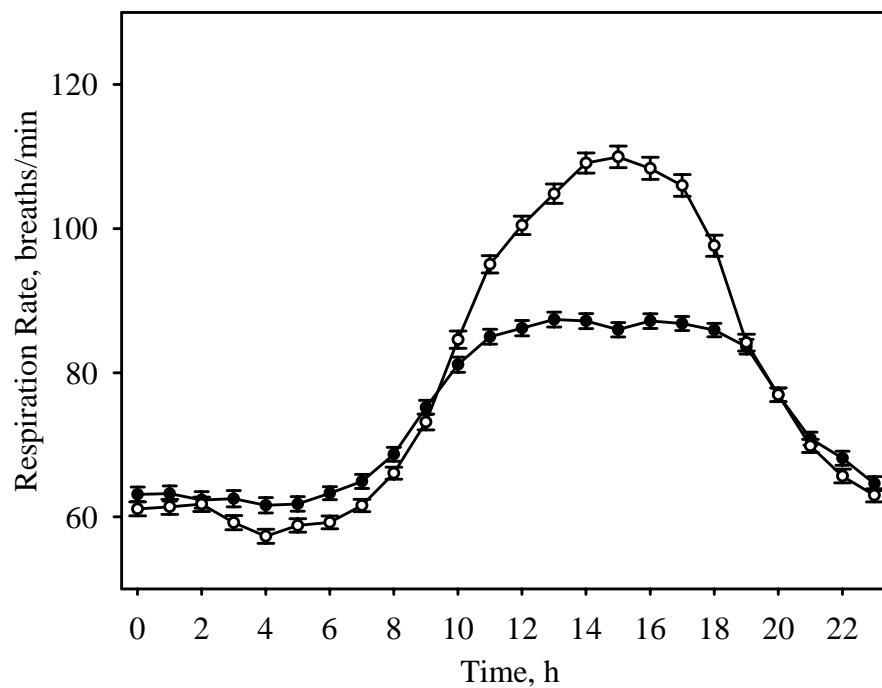


Figure 5. Respiration rates for steers in a 2001 study summarized over eight experimental periods of 4.5 day duration showing shade (●) and no-shade (○) treatments with standard error (midnight = 0) (Eigenberg et al., 2005).

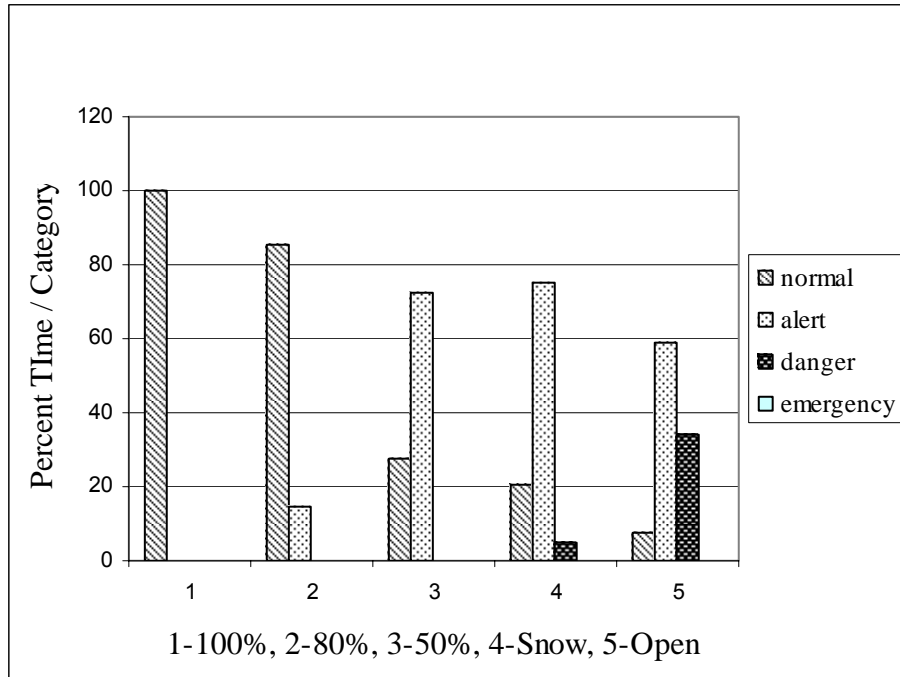


Figure 6. Total time in each stress category under each treatment was converted to percentages. All shade treatments resulted in a reduction of stress compared to no-shade.